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PATENT SPECIFICATION

DRAWINGS ATTACHED

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COMPLETE SPECIFICATION

Aircraft Structural Fatigue Alleviators

We, ELLIOTT BROTHERS (LONDON) LIMITED, a British Company, of Century Works, Lewisham, London, S.E.13., do hereby declare this invention, for which we pray that a Patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

This invention relates to a system for reducing peak wing stresses which occur in an aircraft structure due to carrying out 'g' manoeuvres or flying in rough air, or for means for minimising the fatigue effects of manoeuvring or flying in rough air. The system is of particular value in the case of certain types of aircraft which are flown mainly at low altitudes.

In the preferred embodiment of the invention the aircraft is provided with lift-varying control surfaces, such as ailerons, at or near each wing tip and for the purposes of this specification such control surfaces will be referred to as "alleviators". The terms x-axis and z-axis will be used with their normal aerodynamic meaning, i.e. these axes are fixed in the plane of symmetry of the aircraft and are mutually perpendicular, the rolling or x-axis substantially coinciding with the fuselage datum line and the z-axis being the axis of yaw.

According to the invention a system for reducing structural fatigue damage which would otherwise occur in an aircraft structure as a result of repeated stressing of the structure comprises means for sensing the corresponding flexural accelerations associated with such stressing and means for signalling the accelerations so sensed to means which will actuate aerodynamic surfaces so as to oppose such accelerations.

The invention also include apparatus necessary for the carrying out of the system.

[*Price 4s. 6d.*]

The term structural fatigue damage in this specification and claims means the fraction of fatigue life expended. Fatigue life depends on the number of fluctuations in e.g. aircraft wing roof bending moment as well as the r.m.p. value of these fluctuations.

The invention also includes apparatus for operating the system, such apparatus comprising three z-axis accelerometers substantially in the same position measured in the x-direction and located one in or near each wing tip and one in the plane of symmetry of the aircraft and computing and closed-loop servo systems arranged so that the output of the accelerometers operates alleviators in such a way as to alleviate structural stresses.

An aircraft having the system and apparatus of the invention is also included as being within the scope of the invention.

The preferred embodiment and variations thereof will now be described by way of example with reference to the accompanying drawings in which:—

Figure 1 is a general view of an aircraft equipped with the alleviating system;

Figure 2 is a block diagram showing the overall principle of the invention; and

Figures 3, 4 and 5 are block diagrams showing different embodiments of the invention.

Referring to Figure 1 an aircraft is indicated in general by the reference numeral 1. The x-axis 2 is shown as being inclined at a small angle to the fuselage datum line 3 and the z-axis 4 is perpendicular to the x-axis 2. Accelerometers, 5, 6 and 7 are fitted at the port and starboard wing tips and in the plane of symmetry of the aircraft respectively so as to measure acceleration in a direction parallel to the z-axis. The accelerometers are substantially in the same position fore-and-aft i.e. measured in the x-direction. Alleviators 8 and

9 are provided at the port and starboard wing-tips respectively.

In the block diagram, Figure 2, air turbulence 10 acts on an elastic aircraft 11 so as to produce wing flexural accelerations 12 leading the wing flexure 13 and resulting wing root fatigue stress 14. The closed alleviating loop is shown as starting from the aircraft 11 and proceeding through the wing flexural accelerations 12, the wing tip and central accelerometers 15, the alleviator actuators 16, the alleviators 17, the aircraft aerodynamics 18 and back to the aircraft 11.

Denoting the outputs of the port, starboard and central accelerometers by a_p, a_s, and a_c respectively, then for a hypothetical structurally inflexible aircraft in symmetrical flight $a_p=a_s=a_c$. As a result of the structural compliance, specifically wing bending, of an actual aircraft the values a_p and a_s, equal as before now differ from a_c and the equal differences a_p-a_c and a_s-a_c are measures of wing bending and may be used to deflect the alleviators in the sense to reduce this bending. The fact that the 'flexural accelerations' a_p-a_c, a_s-a_c have 180° phase advance relative to wing flexural deflection or wing root bending moment, and that only a very small (aerodynamic) lag exists between change of alleviator control angle and the corresponding change of local wing lift, enables such deflection of the alleviators to reduce fluctuations in wing root bending moment. The symmetrical flight case is an abstraction and in practice the signals a_p-a_c, a_s-a_c will differ due to aircraft angular acceleration in roll or to excitation of anti-symmetric wing bending modes.

Figure 3 shows diagrammatically one way of performing the invention, in which the port and starboard alleviator control demands are $k(a_p-a_c)$ and $k(a_s-a_c)$ respectively before shaping. Figure 4 shows another way of performing the invention in which the demands are initially for pitchwise alleviator control angles of $k_1 [\frac{1}{2}(a_p+a_s)-a_c]$ and rollwise alleviator control angles of $k_2 [\frac{1}{2}(a_p-a_s)]$ but the demands for port and starboard alleviator control angles must again separately be computed and fed to the respective electro-hydraulic actuators. This way is more complex than the first, being equivalent to it only if $k_1=k_2=k$ when 'pitch+roll' demand becomes $k(a_p-a_c)$ and 'pitch−roll' demand $k(a_s-a_c)$. In the general case where k_1 and k_2 are unequal the demands for port and starboard alleviator angles are respectively

$\frac{1}{2}(k_1+k_2)\, a_p+\frac{1}{2}(k_1-k_2)\, a_s-k_1a_c$ and

$\frac{1}{2}(k_1-k_2)\, a_p+\frac{1}{2}(k_1+k_2)\, a_s-k_1a_c$. shaping apart.

This extra complication is reflected in the enhanced flexibility whereby the gains k_1 and k_2 in the pitch and roll channels respectively are at choice whereas in the first system these gains are esentially equal.

The special case $k_2=0$ is noteworthy; the demands to both alleviators are then $k_1[\frac{1}{2}(a_p+a_s)-a_c]$, shaping apart, and are thus purely pitchwise. The demands of this type of control are most simply met by the arrangement shown in Figure 5.

It will be appreciated that in Figures 3, 4 and 5 the details of known servo art such as feedback loops have been omitted for the sake of clarity. The values of the gains K, K_1 and K_2 and the detailed design of the shapers, usually in the form of RC filters, are chosen to give optimum alleviation in each application but these choices are not quantitatively critical.

All embodiments of the system have the advantage that the operation is unaffected by either a constant 'g' as in steady turning flight or by angle of climb or descent, the system having high-pass characteristics by virtue of the manner in which the accelerometer outputs are differenced. Operation is also unaffected by angular velocities of pitch and roll which are not 'seen' by the accelerometers. Angular acceleration in pitch gives a negligible alleviator demand because, as previously stated, the three accelerometers are substantially in the same fore-and-aft position.

In addition to alleviation of wing root bending moment there is a reduction of wing root shear stress via the lift change due to movement of the alleviators. If greater alleviations of bending moments or shear stresses, particularly the latter, are required then one or more sets of controls inboard of the alleviators described may be operated in sympathy, completely or only pitchwise, with the alleviators.

Operation of the alleviators has virtually no effect on the pitching of the aircraft whose natural frequency is very much lower than the natural frequency of wing flexure alleviated by means of the invention. Hence the invention may be operated in conjunction with a pitch autostabiliser system with negligible coupling between the two whether they use the same or different control surfaces.

Operation of the invention brings about a large increase in damping of the wing first bending mode (modes near the roots) with an accompanying reduction in frequency. The acceleration response of the aircraft to an isolated gust is thereby reduced, as also is the first peak of consequent wing bending.

In rough air there is a significant reduction in both the average (root means square) fluctuation of the wing root bending moment about the calm air value and in the frequency of fatigue-generating fluctuations of this load.

In manoeuvres where 'g' is applied by the pilot or autopilot the invention reduces the peak values and fluctuations of wing root bending moment without affecting however the fundamental aircraft stability and control characteristics — in particular the values of

stick movement and force per 'g' are unaltered.

WHAT WE CLAIM IS:—

1. A system for reducing structural fatigue damage which would otherwise occur in an aircraft structure as a result of repeated stressing of the structure comprising means for sensing the corresponding flexural acceleration associated with such stressing and means for signalling the accelerations so sensed to means which will actuate aerodynamic surfaces so as to oppose such accelerations.

2. A system according to claim 1 comprising three z-axis accelerometers substantially in the same position measured in the x-direction and located one in or near each wing tip of the aircraft and one in the plane of symmetry of the aircraft and computing and closed-loop servo systems arranged so that the output of the accelerometers operates alleviators in such a way as to oppose flexural accelerations associated with the stressing of the aircraft structure.

3. A system according to claim 2 in which the output of each of the three accelerometers is fed into an amplifier having two separate output signals one of which operates a port alleviator and the other of which operates a starboard alleviator, each of the two latter output signals passing through a separate shaper into a separate power amplifier so as to operate a separate electrically controlled actuator which in turn operates its respective alleviator.

4. A system according to claim 2 in which the output of each of the three accelerometers is fed into a first amplifier having two separate output signals one of which relates to pitchwise alleviator demand and the other of which relates to rollwise alleviator demand, each amplifier output signal passing into a separate shaper the output signals of which pass into a second amplifier also having two separate output signals each of which relates to combined pitchwise and rollwise alleviator demands, one of which latter output signals operates the port alleviator and the other of which latter output signals operates the starboard alleviator, each of the latter output signals passing through a separate power amplifier so as to operate a separate electrically controlled actuator which in turn operates its respective alleviator.

5. A system according to claim 2 in which the output of each of the three accelerometers is fed into an amplifier having a single output signal passing into a shaper having two output signals, each of the latter output signals passing through a separate power amplifier so as to operate a separate electrically controlled actuator which in turn operates its respective alleviator.

6. A system for reducing structural fatigue damage substantially as described with reference to the accompanying drawings.

7. Apparatus for reducing structural fatigue damage substantially as described with reference to the accompanying drawings.

8. An aircraft having a system according to any of claims 1 to 6.

9. An aircraft having apparatus according to claim 7.

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POINTS ⊙ ARE AT POSITIONS P, C, S OF PORT, CENTRAL & STARBOARD ACCELEROMETERS. PS IS SHOWN INTERSECTING THE AIRCRAFT SYMMETRY PLANE AT O ON THE FUSELAGE DATUM LINE BUT IN GENERAL O IS NOT ON THIS LINE & MOVES VERY NEARLY IN THE DIRECTION O_z WITH WING FLEXING

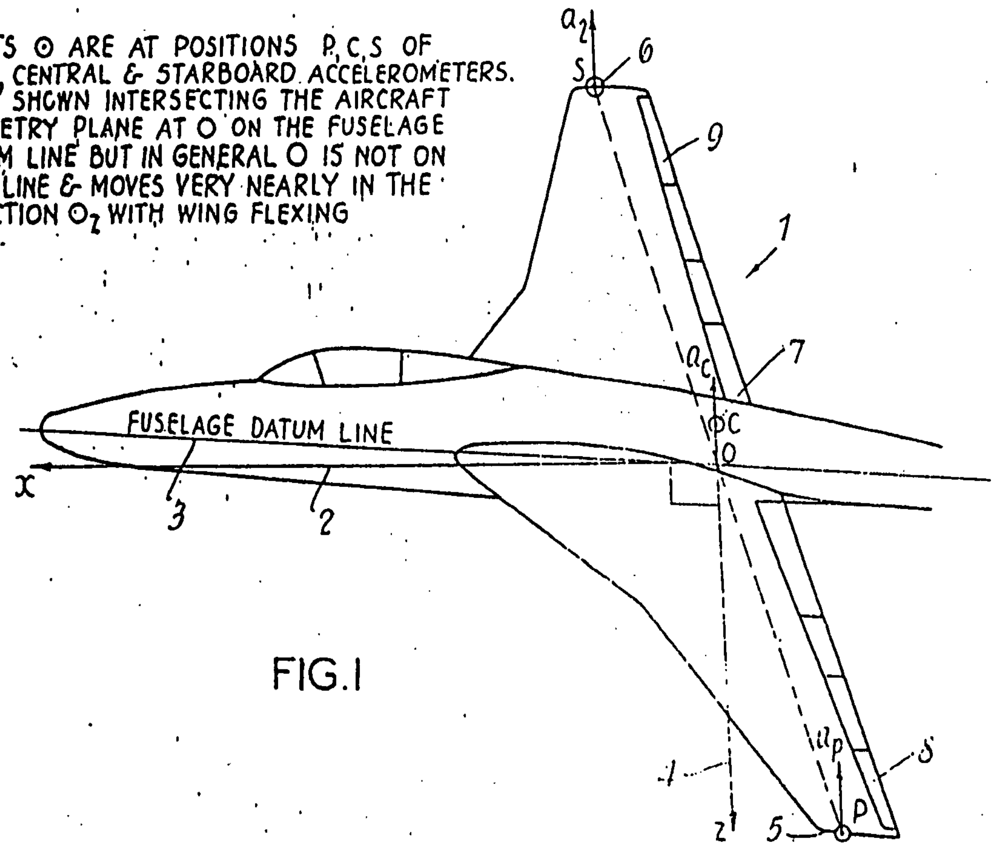

FIG.1

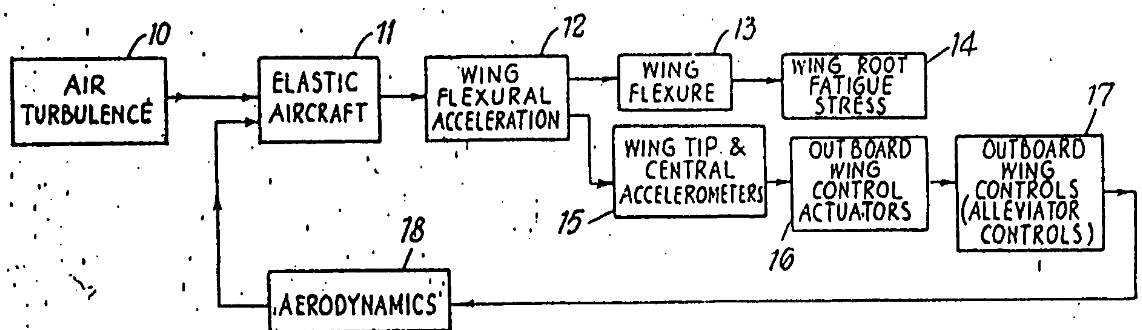

FIG.2